http://dx.doi.org/10.23925/2179-3565.2023v14i3p205-223

RISUS - Journal on Innovation and Sustainability
volume 14, número 3 - 2023
ISSN: 2179-3565
Editor Científico: Arnoldo José de Hoyos Guevara
Editor Assistente: Vitória C. Dib
Avaliação: Melhores práticas editoriais da ANPAD

MESOPOTAMIA: AN ANTIQUE LAND IN DISTRESS

Mesopotâmia: uma antiga terra em perigo

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ABSTRACT

A few thousand years ago, ancient Mesopotamia became the first civilization that engineered water infrastructure to drive native agricultural systems. That civilization created the earliest irrigation systems known to humankind. The ancient Mesopotamians also won success in creating successful irrigation-driven agriculture in arid and semi-arid conditions. Paradoxically, this very success with irrigation systems became a major factor that triggered the collapse of ancient Mesopotamia. We can now infer the Mesopotamians failed to understand the crucial relationships between water, soil, crops, and sound agricultural practices. This lack of understanding continues to the present day. The invention of drip irrigation systems has allowed modern humans to claim some measure of sustainable success in agricultural techniques practiced in desert zones, arid areas, etc. Such techniques enable modern agriculturists to attain a fine balance between soil, crops, and water. Drip irrigation systems also promote other forms of modern innovation such as soilless farming methods and practices.

Keywords: Mesopotamia, Drip Irrigation, Sub-surface Irrigation, Mulching, Hydroponic and Rivers

ACEITO EM: 10/08/2023
PUBLICADO: 20/09/2023

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Mesopotamia: an antique land in distress

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RESUMO

Há alguns milhares de anos, a antiga Mesopotâmia tornou-se a primeira civilização a projetar infraestruturas hídricas para impulsionar os sistemas agrícolas nativos. Essa civilização criou os primeiros sistemas de irrigação conhecidos pela humanidade. Os antigos mesopotâmicos também obtiveram sucesso na criação de uma agricultura bem-sucedida baseada na irrigação em condições áridas e semiáridas. Paradoxalmente, este mesmo sucesso com os sistemas de irrigação tornou-se um factor importante que desencadeou o colapso da antiga Mesopotâmia. Podemos agora inferir que os mesopotâmios não conseguiram compreender as relações cruciais entre água, solo, culturas e práticas agrícolas sólidas. Essa falta de compreensão continua até os dias atuais. A invenção dos sistemas de irrigação gota a gota permitiu aos humanos modernos reivindicar alguma medida de sucesso sustentável nas técnicas agrícolas praticadas em zonas desérticas, áreas áridas, etc. Tais técnicas permitem aos agricultores modernos atingir um equilíbrio delicado entre solo, culturas e água. Os sistemas de irrigação gota a gota também promovem outras formas de inovação moderna, tais como métodos e práticas agrícolas sem solo.

Palavras-chave: Mesopotâmia, Irrigação por gotejamento, Irrigação subterrânea, Cobertura morta, Hidropônica e Rios

INTRODUCTION

Major rivers and in-land lakes of the world are facing a crisis – these water bodies are on the verge of drying up, while some have already ended their existence owing to a variety of depredations induced by natural processes and human activity. Since the end of World War Two, different nations in every continent have embarked on the race to achieve economic prosperity and eradicate the scourge of global hunger. In the process to achieve these goals, humankind has disturbed the earth's many water cycles, ones that create rain and recharge the rivers; human actions have also disrupted the natural mechanisms that allow rivers to rendezvous with seas and oceans. Both these water cycles are crucial to very existence of the human race on this planet. Additionally, human actions have deforested the planet, adding to the list of climate emergencies that face the human race in present times. The mindless extraction of fresh water from rivers has killed these exquisite water systems, thus boosting salt levels in seas and oceans, affecting patterns of global rainfall, and negatively impacting major sections of terrestrial and aquatic food chains.

Acts of sourcing large volumes of water from rivers are largely driven by the needs of modern irrigation systems. "Irrigation" connotes the process of artificially providing water to agricultural fields in the absence of native water bodies; irrigation is also necessitated by low rainfall incidences in agricultural landscapes. This substitution has ensured continued food supply for the human race at affordable prices. However, at the same time irrigation has also emerged as the major source for use of water resources. According to research, the phenomenon of modern irrigation consumes about 70% to 85% of available water in the world today. The process triggers pernicious problems of soil salinity all over the world, the egregious drying up of rivers, water bodies, and the dangerous phenomenon of uncontrolled depletion of naturally occurring ground water resources.

Since irrigation is as old as human settled civilization, the question arises – did the problem of soil salinity occur in olden times? This represents the key investigation undertaken in this study; this paper focuses on some of the irrigation practices undertaken in various ancient societies.

While conducting the process of review of literature for this paper, the author discovered that Mesopotamia remains one of the earliest instances of human civilization that prospered around river valleys and depended heavily on irrigation processes to power agricultural processes. Irrigation represented the backbone of the prosperity of Mesopotamian civilization. However, the process proved to be counterproductive. The Mesopotamians irrigated their fields and agricultural lands with waters drawn from the Euphrates and Tigris rivers. The processes of such irrigation, in the long run, emerged as key factors that contributed to the eventual collapse of the Mesopotamian civilization. Intense Irrigation created the problem of soil salinity, thus affecting the volumes of agricultural production in the long-term horizon. Irrigation infrastructure such as canals, reservoirs, levees, and weirs (which are the basis of modern irrigation systems) proved disastrous to the core functions of rivers and riverine systems bringing silt to the plains; enhanced levels of soil salinity emerged as a byproduct of such practices. History indicates that the ancient Mesopotamians suffered from the misconception of "more water, more crops", perhaps owing to the fact that the science of assessing crop water requirements was inadequately understood in those remote times. Consequently, we may state that the problem of soil salinity is not new to human civilization.

The reams of rich silt that rivers bring from the mountains comprise a key reason that enabled fabled instances of human civilization to flourish around the flood plains of rivers. This silt settles on the plains in the aftermath of flooding events. The silt also acts as a fertilizer and nurtured development of different aspects of ancient agriculture. Alluvium is a solid, dust-like residue carried and deposited by water, ice, and wind. When the flowing water carries small fragments of rocks, it rubs against the edges and bottom of the stream bed, splitting off more rocks. The particles scarp with each other, getting smaller and smaller, until they become silted up. Glaciers can also erode rock particles to form silt. Finally, wind can carry rock particles across a canyon or landscape, causing the particles to collide with the canyon wall or with each other. All three processes form Alluvium. It consists of rock and mineral particles that are larger than clay but less sand (National Geographic, 2009). However, the water infrastructures have proved detrimental to this function of rivers because the reservoirs that hold water in irrigation systems force the silt to settle down; consequently, the downstream areas get exhausted in the absence of recharging mechanisms typical of silt deposition by naturally flowing rivers. The water infrastructures deployed by the Mesopotamians and the Post-Second World War era proved unfavorable to natural recharging of land fertility by river-borne silt. We must note that reservoirs (and canals) contribute to processes of transporting fine sand particles to agricultural areas; this proves detrimental to the natural fertility of lands, enhances soil salinity, and eventually drives the process of slow desertification.

However, these infrastructures were also the key to enhanced agricultural output – and crop patterns with inclusion of Summer Cropping – by supplying water through surface irrigation systems. Unlike the summer crops raised in humid regions where humid air supplements the water needs of agriculture, the dry air in semi-arid regions promotes water evaporation from the crops through processes of evapotranspiration. This phenomenon encourages farmers to supply excess water to crops in arid and semi-arid regions, thus increasing the strain on natural water resources. Further, unlike trees whose great height assists the completion of water cycles through evapotranspiration, agricultural crops fail to complete the water cycle as evapotranspiration robs them of moisture due to dry climate.

Israel, unlike the rest of the world, chose not to follow the irrigation model of substituting water to raise crops in arid and semi-arid conditions. This stance was necessary because Israel has very dry climate and there are no rivers or noticeable water bodies in that nation. It is only during the rainy seasons that *Wadis* and rivulets have water for the short time. In such scenario, Israeli scientists and agricultural specialists evolved the idea of Drip Irrigation; specifically, the concept was propounded by Simcha Blass in the 1930s. "Waterless" tree brought to the attention of Blass's attention while working on the first modern aqueduct in the Jordan Valley. It took Blass some digging to uncover the source of the tree's water supply, which was a leaky pipe coupler! (My Olive Tree 2017). In faraway India, Jain Irrigation – working without government assistance – developed the concept of Drip Irrigation. This concept works on the model of growing more crops per drop of water, rather than directing flowing streams of water into croplands.

This paper examines the irrigation practices undertaken in ancient Mesopotamia, the connected causes leading to the collapse of that civilization; this paper also highlights various techniques developed and deployed by Israel and Jain Irrigation. These entities helped develop the low water consumption models in the domain of modern agriculture. Such models are particularly important in today's scenario of climate change characterized by extreme weather events including low and erratic patterns of atmospheric precipitation.

1 MESOPOTAMIA

A.D. Greeks dubbed Mesopotamia the territory between Euphrates and Tigris rivers, including their tributaries. It lies in the eastern side of this land termed as "fertile crescent". Upper Mesopotamia and Lower Mesopotamia are the two parts. It is a Piedmont zone in Mesopotamia that borders semi-arid highland, where dry-farming developed. Piedmont is an area at the foot of a mountain or mountain range. The word Piedmont comes from the Italian words pied and monte, which mean foot and hill (National Geographic, 2011). Being close to mountains, the north received annual rainfall of 200mm - 300 mm per year. This amount sufficed rain-fed or dry-farming. The lower Mesopotamia, a *bona fide* alluvial plain, is also flanked by semi-arid climate. It is a region where both the Euphrates and Tigris enter the plains and have low gradient. This enables the rivers to deposit silt from the mountains on the plain, thus raising the height of the river bed when compared to the surrounding land (Tamburrino 2010: 29-31) (Leick 2003: 5) (Bagg 2012: 261-262).

Both the Euphrates and Tigris arise in the region of Armenia. To the northwest of Lake Van lies the confluences of the Kara (western Euphrates) and Murat (eastern Euphrates), forming the 2,800-km-long Euphrates. On its way to Syria and Iraq, it runs south-west through Turkey and then switches direction to the south-east. The Tigris River (1,950 km) rises near Mount Ararat and flows south-east almost immediately. Both the rivers share a common mountain heritage – the Taurus mountains, and are separated from each other by a distance of about 400 km. A mere 32 km separates them near Baghdad. They diverge again shortly thereafter and reconnect in Qurnah, 100 km north of Basrah. The two merges in Basra to form the Shatt-el-'Arab (Arabian River) which flows for about 220 km before reaching the Persian Gulf delta. The Tigris floods are unexpected and devastating, whereas the Euphrates floods are less severe and occur primarily in April and May (Tamburrino 2010: 30) (Bagg 2012: 262-263).

The south/lower Mesopotamia, being distant from mountain ranges and in close proximity to the western desert, suffers from incidence of low rainfall. The north/upper Mesopotamia is formed by limestone and alluvial deposits, the south/lower or Babylonia is plain and lacks stones; it also experiences the low gradient of rivers, and therefore carries thick deposits of alluvial sediment. The north/upper Mesopotamia bears the clay-rich alluvial soil where agricultural exploitation was possible only through irrigation and guaranteed abundant and multiple crops of barley and emmer wheat. This acted as a driver of population growth and generated surplus food grains in the south. The south being gravel-free proved advantageous for ploughing activity and for construction of canals and subsidiary waterways. However, the semi-arid climatic condition with hot summers proved counter-productive for campaigns of intensive date-palm cultivation, a source of high energy nutrition and timber (Leick 2003: 6-7) (Hole 2007: 194).

In Mesopotamia, cereals were grown in winter from October to November, and harvested from April to May. This agricultural pattern is not followed by the Twin Rivers regime. The water level is lowest when it is most needed (September - October) and the spring floods coincide with the harvest months (April - May). Floods in late spring just before harvest proved catastrophic for standing crops. Therefore, Mesopotamia didn't suffer from shortage of water but from irregularity and unpredictability of the water supply. During floods, both rivers deposit large amounts of sediments. A natural levee is formed by this silt, which lifts riverbed above the surroundings. Fine particles can settle to the soil surface or penetrate deeper into soil layers, preventing water from entering and seedlings emerging. The two rivers were vital to farming in arid and semi-arid conditions and carried silt six times the volume of silt borne by the river Nile. This made their river beds shallower and they changed courses more often thus making their floods more violent, spilling over the banks and washing away the fields. We must note these are fast flowing rivers, the Tigris being faster than the Euphrates (Bagg 2012: 263) (Mohammed 2014: 2014).

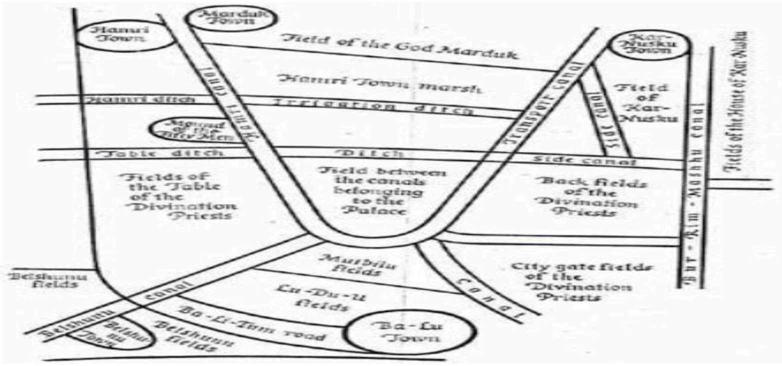
Figure 1 - Greater Mesopotamia (Tamburrino 2010:30)

Irrigation comprises artificial techniques that supply water to agricultural fields. There are different types of irrigation techniques that vary with regard to modes of distributing water to fields. In Mesopotamia, surface irrigation was deployed distribute water along the fields using gravity flow techniques. Open distribution systems were used to disperse the water, unlike pipe distribution systems. At the field's upper edge, open canals were built from which water could be directed into basins or furrows. As far as surface irrigation systems are concerned, there were two basic types: basin and furrow (*Bagg* 2012: 266).

Basin irrigation was the most basic method and was widely used in Mesopotamia. Fields were divided into units with a virtually flat surface in this approach. Around the fields, levees (earth banks) were built, generating basins. After reaching the proper depth, water is channelled into basins where it is kept until the soil is saturated and excess water is drained away. Furrow irrigation systems work by allowing water to run through narrow channels (furrows) that convey the water down the field's prevailing slope. Water applied to the top end of the furrows sweeps into the bottom and sides, providing crops with the moisture they require. In contrast to basin irrigation, the entire soil surface is not wetted. This method prevented excessive application of water, thus arresting the spread of soil salinity (*Bagg* 2012: 266-267).

The climate of the lower Mesopotamia is such that it brings floods during the months of April and June every year. The warming of climate starts from March, which causes flooding in these two rivers. This flooding is too late for the winter crops that are ready for harvest, and too early for summer crops as the land is left fallow after the winter crops. Therefore, for the success of agriculture in semi-arid Mesopotamia, it became imperative to hold water throughout the summer months for use to grow winter crops. This led to the birth of irrigation, a set of engineered processes that depended on the system of canals, reservoirs, dykes, and levees to ensure continued water supply. The canals in Mesopotamia had dual purpose to ensure irrigation, as also to facilitate regional trade through waterways. The example of such canal is that of Idninashdu canal fed by the waters of the Euphrates. It connected the cities of Nina, Lagash, Girsu, and Zabalam (Tamburrino 2010: 31-34) (Mohammed 2014: 20). The figure below illustrates the pattern of canals in Mesopotamia.

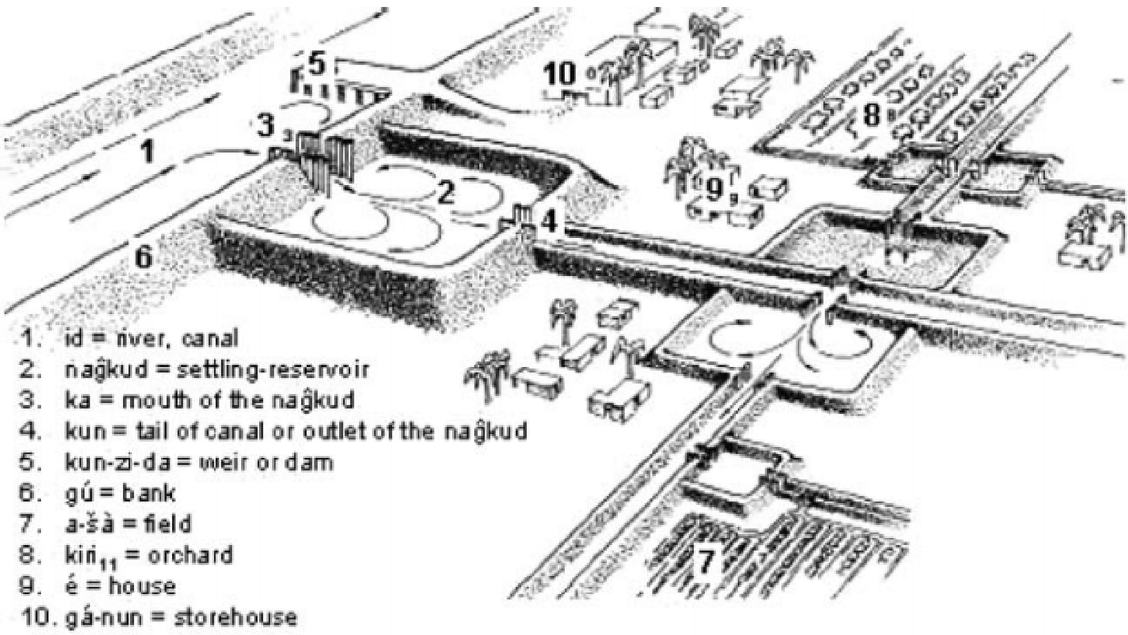
Figure 2 - The Canal System in Mesopotamia (Mohammed 2014: 44)



Sennacherib, a king that ruled from 705 BC to 681 BC, solved the problem of flooding by building artificial marshes, thus creating a swamp with reed plantations. The marshes would help to recharge ground water levels, and at same time stored water for subsequent irrigation practices (Tamburrino 2010: 37-38).

The Sumerian language is yet to be deciphered completely. A study of the term nagkud (nagkud) by S.T. Kang, on the other hand, provided a picture of Mesopotamia's canals and irrigation system. He came up with a design for a multi-purpose settling reservoir (Fig. 3). In addition, it served as a reservoir and facilitated crossings to restrict the flow of water from upper riverbeds to lower plains.

Figure 3 - The settling-reservoir (nagkud) and complementary water-works as reconstructed by Kang S.T. from the Ur III texts. (Tamburrino 2010: 44).



Kang points out that these settling reservoirs were primarily the settlement basin meant for storage and regulation of water for dry seasons. The size of these nag-kuds varied from 12m length, 6m width and 3m height to 72m length, 12m width and 5m height. The mouth of this system Ka 3 was designed to avoid erosion from main canal or a river; hence, it was narrow with a width of 1m and a length of approximately 36m. As can be observed from the figure, there are several retention reservoirs before the water enters the field. These reservoirs stored the water but at same time held back the silt from the main canal or a river. Their efficiency was reduced owing to their open configuration, leading to loss of water by evaporation. Even in those times, the silt laden water was preferred to clear water (Tamburrino 2010: 44).

1.1 The Rise of State

Mesopotamians first ventured to control the Euphrates; this choice of action was governed by the fact the river has a flat gradient, thereby making for easy taming of this water body. Despite Mesopotamia's flat terrain, the Euphrates' bed is higher than the Tigris'; in fact, Euphrates floods occasionally made their way across the region into the Tigris (Blackwell et.al. 2004: 1) (Christensen 1998: 17). This resulted in a surge in agricultural production and winter wheat emerged as primary crop of the Mesopotamian civilization. This irrigation system of canals and reservoirs necessitated the system of regular maintenance. Such imperatives formed the basis for the rise of strong central political authority in the region, as a mechanism to marshal the resources that helped propagate the successful continuity of native agricultural systems. Instead of helping floods by reducing or eliminating flooding, this system of canal branches and flood protection structures exacerbated silt deposition processes and led to over irrigation, as pointed out by Jacobsen and Adams in the literature mentioned in Tablet I of Atra-Hasis epic '...the black fields became white, the broad plains choked with salt...' (Tamburrino 2010: 47-48).

Table I - List of Crops grown by Mesopotamians (Agricultural sustainability in the semi-arid Near East, Hole 2007: 194)

S. No.	Crops	Scientific Name
1	Emmer wheat	*Triticum Dicoccoides*
2	Einkorn wheat	*Triticum Monococcum*
3	Barley	*Hordeum Distichum*
4	Lentil	*Lens Culinaris*
5	Pea	*Pisum Sativum*
6	Chickpea	*Cicer Arietinum*
7	Flax	*Linum Usitatissimum*
8	Bitter vetch	*Vicia Sativa*

These canals from the Euphrates guaranteed prosperity due to increased agricultural production, but also became the center for political conflict for control among the various Mesopotamian States. Irrigation in the Mesopotamian floodplain started around 5,000 BCE. The region's people redirected irrigation water using canals that largely matched the flow of the Euphrates during the first several thousand years. Therefore, the area around Euphrates became major center of settlement and cultivation. Mesopotamia introduced new irrigation technologies around the middle of the first millennium BCE, which radically altered the floodplain's natural topography and ecosystem. Five vast feeder canals diverted Euphrates waters across the middle floodplain into the Tigris, while two massive, interconnected parallel diversion canals, the Katul alKisrawi and Nahrawan Canal, tapped the Tigris as a major source of agricultural water hence the first interlinking of rivers (Christensen 1998: 17) (Butzer 2012: 3635).

1.2 Riparian Rivalry & Problems with Irrigation

An ongoing struggle between Umma and Girsu over a fertile border territory watered by the Euphrates made tapping the Tigris inevitable. Umma, being the upper riparian state, controlled the water supply to Girsu. This led the rulers of Girsu to look at Tigris, which was still untamed comparatively. They built large canals to bring water from the Tigris, allowing them to be independent of the Euphrates' limited water supply. This strategy made Girsu independent of the Euphrates River and from the Umma interference, but proved counterproductive. The length of the canal, being long, enhanced the problem of seepage from the main canal thus leading to rising saline ground water levels. The availability of more water led to the problem of over irrigation and further aggravated soil salinity; it also brought the problem of flooding direct to the field because the bed of Tigris lies at a plane higher than the surrounding landscape. The irrigation though diversified the cropping pattern by intensifying agriculture to cultivate even during summer months. These measures led to the problem of soil salinity as Mesopotamia suffered reverses in agricultural production circa 2400 BC. to 3500 BC. The region experienced major change in the cropping patterns of wheat and barley, the main crops of this civilization. The soil salinity led the natives to abandon wheat, and for thousands of thereafter, barley accounted to account for 80% of agricultural production in Mesopotamia. The other outcomes were soil salinity and siltation. Now the land had to lie fallow for longer duration of time, since most of Mesopotamian landscape was alluvial plain – with high clay content in the soil disturbed by low deposition of river silt; it had more holding capacity of water and had to be left fallow for the salt to percolate down and the landscape to regain soil fertility. (Tamburrino 2010: 48-49) (Christensen 1998: 15-19).

Salinization was, therefore, one of the most likely reasons why in the second and first millennium BC. Important settlements, cultural influence, and political power moved to Babylon in Upper Mesopotamia. According to textual evidence, barley (Hordeum vulgare) replaced wheat (Triticum spp.) as the primary crop in parts of the alluvium. The key reason behind this was the fact barley is more salt tolerant (FAO 2012) than wheat, and hence it increased its proportion in Mesopotamia's food basket. Due to salinization, wheat was no longer the most popular crop. Altaweel points out the observation of Jacobsen and Adams observation from various tablets about the decline in wheat crop yields is was experienced in Lagash (Girsu). Yield of wheat was 2537 liters per hectare approximately in 2400 BC, which declined 1460 liters per hectare by 2100 BC. By approx. 1700 BC, wheat yields in Larsa had dropped to an average of 897 liters per hectare in another portion of the plain. Maekawa (1974) also attributes the decrease in yield to seed rationing, claiming that the loss in productivity was already evident in the vicinity of Lagash at the end of the Akkadian period (2334-2154 BC). In the fields of Mesopotamia around 2350 BC, the cultivation pattern was as follows: barley 80%, emmer 15%, and wheat 0.6 percent.

The proportions were as follows during Shulgi's period (2094 BC - 2047 BC): barley 97.8%, emmer 1.7 percent, and wheat 0.2 percent (Altaweel 2013: 1-2).

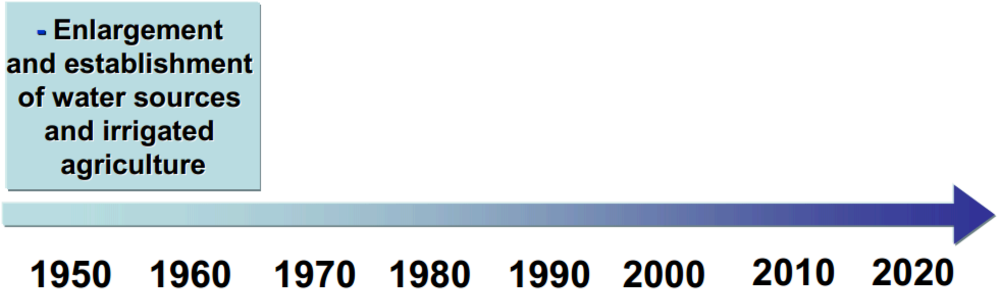
Salinization is the totting up of sodium chloride in the texture of agricultural fields. As a result of the high clay concentration, it occurs in locations with poor drainage as well as in river valleys. Reduced silt accumulation, naturally high levels of salt in soils (e.g., saline-alkali soils), as well as excessive irrigation water stripped of the silt, limited rainfall, a high-water table, insufficient crop water uptake, and high levels of evaporation all contribute to this condition. Salinity also spikes in areas away from river basins where clay content is naturally higher due to the absence of river-borne silt. Salt is introduced to the root zone of agricultural crops by irrigation water, capillary rise in locations with high water tables, and evaporation. The lack of rainfall (or water used to leach salt from fields) prevents effective removal of salt from soils. As a result of poor drainage caused by clay content, water remains stagnant on fields, and evaporation concentrates the salts. Hot, dry weather, such as that experienced in lower Mesopotamia, ensured that evaporation rates acted fast to concentrate salt on the surface of the Euphrates and Tigris rivers' waters (Jacobsen & Adam 1958: 1251). Furthermore, crops may not be able to transpire at a high enough rate to ensure that water is cleared from fields before salts are deposited (Altaweel 2013: 3).

Climate conditions in the late third millennium and early second millennium BC were hot and dry, necessitating agriculture heavily reliant on irrigation. Salinity of irrigation water would have been relatively high in this scenario due to lesser rainfall, which would have resulted in higher salt concentrations and lower leaching. Great irrigation networks that supported large populations in Mesopotamia were fragile because they were artificial, i.e., relatively homogeneous, managed, and hierarchical systems that required a lot of capital or labour to maintain and an even bigger amount to rebuild. Experts have stated that the desert may reappear after desertion, not due to environmental degradation, but due to human disengagement. The period from 2600 BC - 2000 BC witnessed the advent of arid conditions leading to excessive irrigation culminating in soil salinity triggering falls in production (Altaweel 2013: 7) (Jacobsen & Adams 1958: 1251) (Butzer 2012: 3636) (Minaev & Maslov 2009: 5-6) (Bagg 2012: 269) (Hole 2007: 197). Hence, water which was *prima matter* for the success of the civilization – eventually became one of the factors that triggered its collapse (Tamburrino 2010: 48-49).

2 THE ISRAEL EXPERIENCE

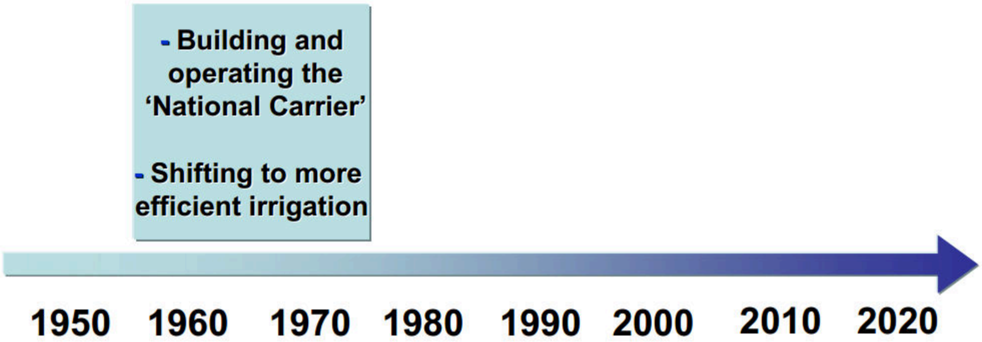
Land and water resources in Israel are public assets. The journey of Simcha Blass and the discovery of the Olive Tree flourishing in the desert (because its roots received water from an underground pipe) lead to the development of the concept of drip irrigation. Blass patented the technology in 1959. Prior to the discovery, drip irrigation systems started in Afghanistan in 1866, when researchers experimenting by interring clay pots filled with water within the planting area (Dirpdepot 2017). The process has a long history of trial and errors, but various legislation s enacted by the Israeli government ultimately popularized the paradigm of drip irrigation. It started with setting up of 'Mekorot' in 1950s, the National Water Company for Water Conveyance and Distribution Systems, Public Agriculture, Research and Development and Extension Services. In the beginning, the sources of fresh water were identified for irrigated agriculture.

Figure 4 - Irrigated Agriculture in Israel - Milestone 50's - mid 60s (MARD 2010: 3)



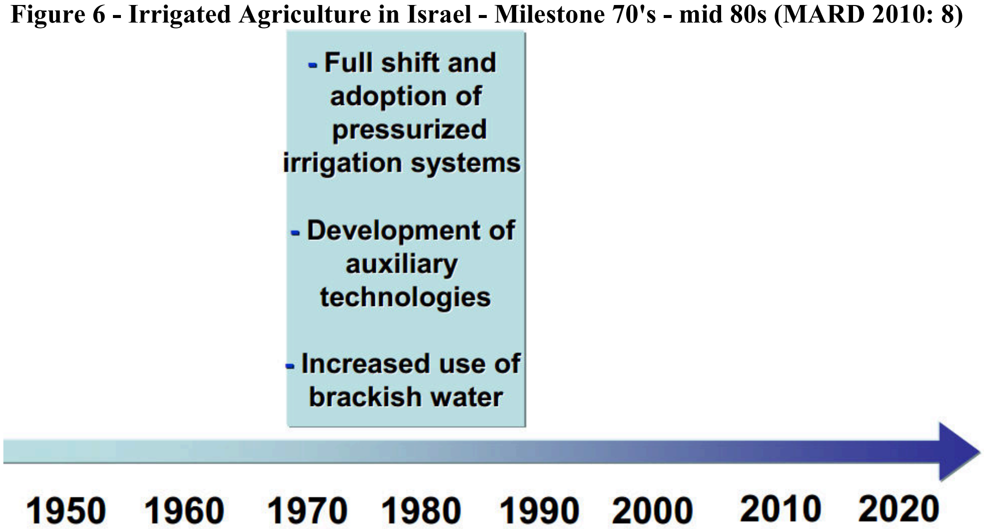
With setting of Mekorot, the Israelis matured their water delivery systems to pressurized irrigation as it facilitated drip irrigation and led to higher levels of efficiency in the use of water. This process subsumed the decades of the 1960s and the 1970s.

Figure 5 - Irrigated Agriculture in Israel - Milestone 60's - mid 70s (MARD 2010: 5)



The formalization of water delivery systems and advancement in plastics enhanced the drip irrigation system. By the 1970s, Israel won recognition as a nation from several members of the international community, and the process of Jews Migration from all corners of the world to Israel reached its zenith. This process led to population explosion in Israel, leading to growing demand for food and resources. . With limited sources of fresh water, the Israeli government looked for alternative source of water; this triggered the use of drip irrigation systems be in wedded to pressurized supply of water. The new source of water came from brackish water and saline sources. The source of brackish water was from municipal use, which was treated to make it suitable for use in agriculture. The source of Saline water came from Sea of Galilee, a saltwater lake water where Israel had deployed reverse osmosis technology to treat saline sea water. Both sources proved very beneficial as they augmented the pressurized drip irrigation systems. Due to this, water use efficiency increased by 80% to 90% compared to 40 % to 50% efficiency of surface irrigation.

Figure 6 - Irrigated Agriculture in Israel - Milestone 70's - mid 80s (MARD 2010: 8)

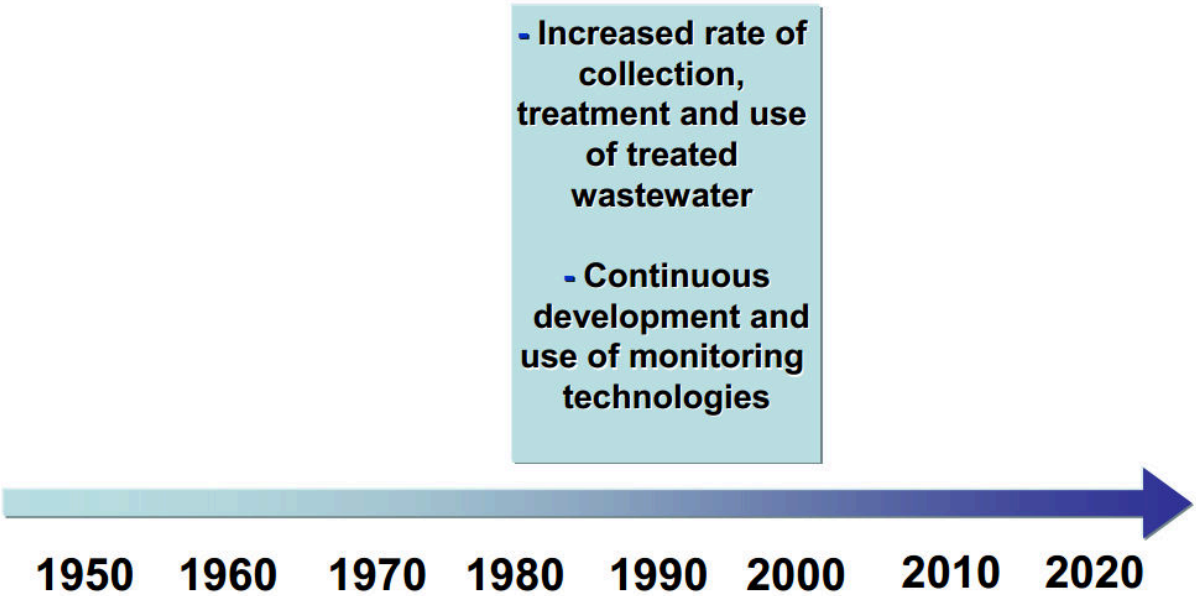


Pressurized Agriculture

Figure 7 - Pressurized Agriculture (MARD 2010:10)

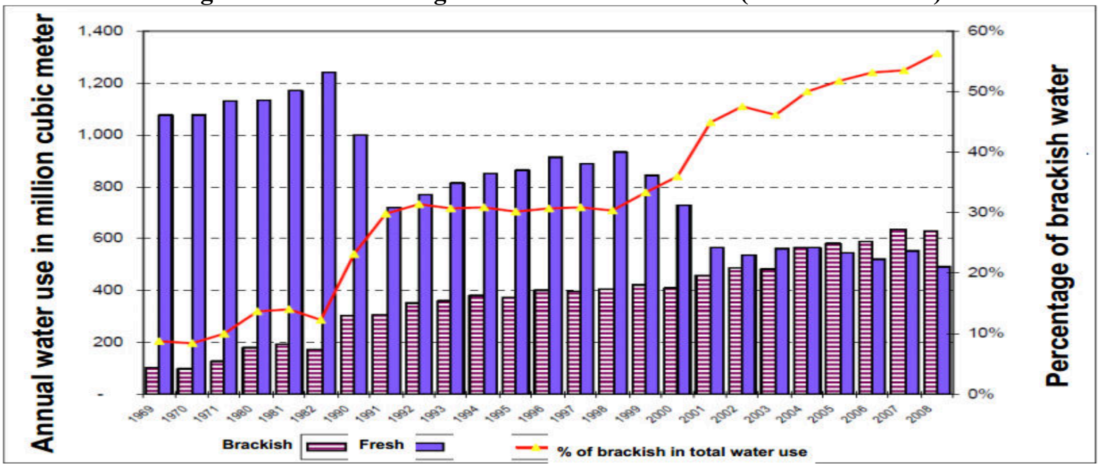
The closing years of the 20th century and beginning of 21st century brought the issues of climate change in Israel as rains were failing, leading to conditions of drought. This forced Israel to devise further advances in reverse osmosis technology for desalination of ocean water and enhancement of sewage/municipal water. Israel achieved this by recycling up to 80% to 90% of municipal water, by rationalizing water use by shifting to more drought prone crops, and increasing efficiency in collection of rainfall to recharge natural aquifers in the region (Horovitz 2013) (Alon Tal, 2016; pg-388).

Figure 8 - Irrigated Agriculture in Israel - Milestone 80's - late 00's (MARD 2010: 18)



Irrigation and agricultural technologies have been homogenized in Israel and is on the path of continual refinement. Such technology promotes the collaboration of stakeholders for identifying constrains, solutions, know-how adaptation, and diffusion of technologies. It is pillared on efficient and economic, yet sustainable management. It's an ongoing process in Israel, a nation that imparts this knowledge to the rest of the world with its 'Meshav' program. The figure below exemplifies the rise in use of sewage/municipal water over the decades.

Figure 9 - Water for Agriculture from 1969-2008 (MARD 2010: 28)



2.1 Drip Irrigation

It describes a system of delivering minuscule amounts of water and water soluble ingredients steadily and directly to the root zones of plants and trees. One of the primary reasons of crop loss lies in the growth of parasites (both insects and plant) that feed on crops. The surface irrigation augments their growth by providing the humid environment for parasitic growth. To counter this, drip irrigation is applied directly to roots in tiny quantities, therefore arresting any unwanted spillover and thus the rest of the area of the field remains dry. This technique arrests weed growth and pest growth in the field. Further, fields with row cultivation require water discharge or runoff systems, this is eliminated through drip irrigation techniques, thus saving costs otherwise incurred in leveling of agricultural fields. In addition, drip irrigation grants freedom from fertilizer-induced pollution of local water bodies as there is no run off from agricultural fields (Tal 2015: 388).

2.2 Subsurface Drip Irrigation (SDI)

SDI refers to the application of water below the soil surface via emitters at the same pace as drip irrigation. The SDI was first experimented in the US in 1959 in the states of Hawaii and California (Camp & Lamm 2014: 560). The age of plastics imparted a boost to SDI and Israel perfected the system. The system helped in efficient utilization of municipal treated water. Firstly, it solved problems of aesthetic and hygiene issues related to sewage water use. With the coming of plastic emitters, the problem of clogging the water holes was also removed (Tal 2015: 389). The best example of SDI is its application for Rice cultivation. Rice as a crop is associated with paddies and profuse water supply and standing water in the fields enough for fisheries. By deploying SDI there is no need of flooding the fields. This technique sharply reduces the problem of salination, thereby helping agriculturists to evade the dangers posed by flooding which leads to water penetration in sub soils and the consequent triggering of capillary rise of salt to top soils. In addition, SDI prevents water runoff from the fields, thus preventing fertilizer pollution of local water bodies and ground water. It also helps in mitigating climate change because conventional rice cultivation techniques generate four times the greenhouse gas emissions of maize or wheat, contributing over 1% of global greenhouse gas emissions. The field trials in Israel and India have demonstrated reduction by half in emission of methane and other greenhouse gases (Tal 2015: 389).

In conventional paddy cultivation techniques, about 1300 mm - 1600 mm of water per season is used. In the delta areas of India, water consumption rises to about 2000 mm of water in paddy cultivation. This accounts of almost 80% of irrigation water. The SDI helps to reduce water consumption for rice cultivation by 50%, it reduces the water application to 750 mm - 800 mm of water per season. The advantage of this system is application of water directly to the crop; this technique also reduces wastage by spillage. Hence, we may state SDI significantly arrests the problem of salinity in modern agriculture (Jain Irrigation 2014).

The on-farm trial with SDI at Gumthala Garhu village of Kurukshethra district, Haryana India, demonstrated that PR 126 rice variety registered considerable increase in yield per hector. *The yield achieved with SDI was 6950 kg ha$^{-1,}$ and in case of flood irrigation it was 6225 kg ha^{-1}. The water use efficiency that crop per millimeter of water was therefore 170% better for SDI, it was 17.1 kg/ha/mm in case of flood irrigation it was 10.6 kg/ha/mm* (Bansal et.al. 2018: 510).

2.3 Squeezing Water from Air

In its endeavors to find alternative sources of water, Israel has pioneered some ways like artificially seeding clouds for rain, municipal water recycling systems, and - more recently - harvesting of atmospheric air for water. The figures below are instructive.

Figure 10 - Lemon Tree Plantation With and without Try (Tal-Ya)

Figure 11 - The Dew Collecting Try (Tal-Ya)

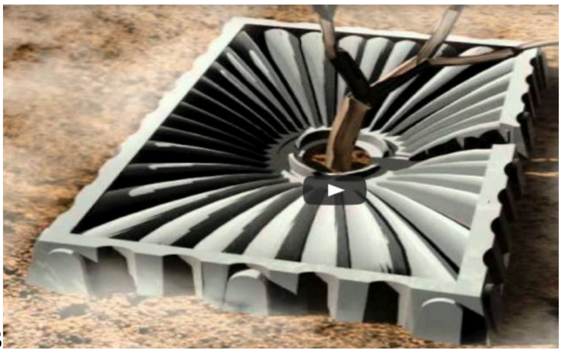


Figure 12 - Arava R&D Centre (Leichman 2019)

3.3

A plastic tray collects the dew and moisture from the air during the night as temperature cools down and directs it to root zone of the plant. Further, it prevents the growth of weeds around the plant. The field experiment with lemon crop highlights the advantage of this technology in the figure above. It is an effective tool for harnessing water from alternative sources especially in hot and arid regions. We may recall due forms when the air saturated with water vapor cools down or reaches the point where it cannot hold water and water condenses to form droplets. Twenty grams of water vapor per kilogram or 2% of air mass is ideal for dew formation (Lallnailla 2014) (WeatherStreet 2019). Kothara Kothara - located in Abdasa Taluka of Kutch district of Gujarat, India - produces about 0.71 liters/m2 per night 103 days equates to 73.1 l/m2 per annum. A surface of 10 m2 would be able to collect 720 liters per annum. This is approximately the amount of water for 1 person drinking 2 liters per day per annum (Kotzen 2015: 39).

Figure 13 - Model for Dew Harvesting (Adamowski & Khalil 2014: 8)

This image shows Dew Water Irrigation Systems (IDWIS) proposed by Prof. Adamowski's team at the American Society of Agricultural and Biological Engineering (ASABE) International Annual Meeting. IDWIS has received a very positive response from experts worldwide; they asked to build this system in Egypt and in Indonesia (Adamowski & Khalil 2014).

2.4 Mulching

Mulching is one of the subsets of drip irrigation techniques. It is an activity of covering soil surface with a material. It is used to discourage weed growth, retain moisture in the soil, keep the soil cool, trap heat, and reduce runoff losses. Mulching also increases germination percentage, improves soil structure, protects roots from fluctuating/extreme temperatures, and helps control soil erosion (Gardener: 2020) (Telkar, et.al. 2017: 1).

Figure 14&15 - Plastic Mulching (Chrobak 2018)

In one of the field trials at West Bengal, India, a Guava crop showed that the shelf life of the fruit was greater; the initiative brought forth 89% of saleable fruit on the ninth day of storage, while crop without mulching had minimum storage life (Dutta & Majumdar 2009: 175). The table below highlights the field trial results of mulching on guava crop and its effects on fruit characteristics and impact on soil moisture.

Table II - Guava Cropping With and without Mulching (Dutta & Majumdar 2009: 175)

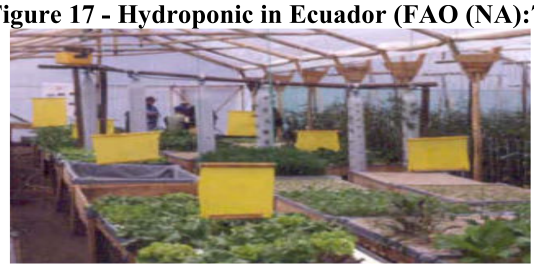
	Fruit Weight (g)	Fruit Length (cm)	Fruit Diameter (cm)	Yield (Ton/hec)	Soil moisture content at 0-30 cm (%)
Black Polythene	100.20	5.72	6.42	7.75	14.00
Unmulched	90.20	5.10	6.10	6.50	3.20

The above-mentioned techniques will help the farmers to undertake water conservation methods. Apart from watering crops, water is utilized in ancillary activities like spraying of fertilizers and pesticides. Biofeed – an Israeli startup – provides solutions to conserving water by eliminating spraying. It's an organic personalised diet that feeds croplands stimulants and medicinal agents; the solution is provided by a unique gravity-controlled fluid release platform to eliminate microscopic flies that prey on crops. It has successfully been implemented to grow mango trees in Tamil Nadu, India (Leichnam 2019). The photo below is an example of the product. The solution also helps to protect useful insects from getting eliminated.

Figure 16 - Biofeed (Leichman 2019)

The technique was also deployed on fields in Ecuador by the FAO project on simplified hydroponic. The picture below illustrates it.

Figure 17 - Hydroponic in Ecuador (FAO (NA):7)



3 HYDROPONIC

It is a system of cultivation, which is soilless. That means a person who doesn't have a farm and lives in urban centers can engage in the activity of crop production. As we have observed from the above paragraphs, the world has watered the soil more than the crops and thus has destroyed the land, deproved rivers of their water, dried up lakes, cleared forests leading to climate change, etc. The word "hydro" has Greek roots meaning water. "Ponic" also comes from Greek word "Ponos". Ponos was the Greek God of hard labor and toil in Greek mythology (Wikipedia).

Mesopotamia is credited with the invention of irrigation system as we know them now, have proved detrimental to their civilization and in post second world war era to the rest of the world. The stark examples of it is the drying of the Aral Sea and alarming low water levels of many lakes around the world and other low run off rivers which struggle to reach their deltas. The following rivers have dried up and fail to reach their delta Colorado; Indus; Amu Darya; Syr Darya; Rio Grande; Teesta; Yellow River and Murray-Darling river (Howard & Borunda 2008). The Yellow River, we may note, was revived with government efforts in China.

The first reference to hydroponic cultivation can be traced to the hanging gardens of Babylon. They were planted on the Ziggurrat. It imitates the mountain steps farming. It was constructed of stone, bitumen, and timber and mirrored the physical structures of Greek theatre. They were not soilless. The water was lifted with a device, which looked like Archimedes screw. The idea of screw came from the palm tree that has a spiral pattern on its trunk, where the old frond had broken away and looked like a screw. The Babylonian name for this palm is 'alamttn' and is identified as *Chamearops humilis*, it exhibits a spiral pattern on the trunk.

Sennacherib (the king) drew inspiration from this spiral pattern, casted it out of copper or bronze from the clay mold, and used the molds to lift water. Archimedes screw imitates it, but it was he who is credited for the invention of screw as it was based on mathematical calculation and with precision the physical principle and its application (Dalley 1993:8). The idea actually never caught up with the Mesopotamians as it was cumbersome and was limited to royal gardens in palaces. Hence, they continued conventional agricultural practices, and ultimately soil salinity emerged to destroy the Mesopotamian civilization. After Mesopotamia, successor civilizations figured out methods to deal with problem of soil salinity by practicing shifting agriculture. This was possible in land with less population, hence originated in Africa. In Asia, the annual river floods recharge the soil every year, hence cultivators in that continent did not practice shifting cultivation. India is the perfect example of river flood land rejuvenating; this country is home to a number of river systems that rejuvenate the land, hence making land very fertile, and thus contributing to the creation of national wealth.

The modern hydroponic model can be traced to William Frederick Gericke who started experimenting with soilless cultivation in pots, is regarded as the father of modern hydroponics. In December 1929, Gericke published an article "Aquaculture: A Means of Crop Production" in American Journal of Botany. He proposed a soilless crop production system designed on a commercial scale. His research never saw practical applications as the world could not conceptualize the idea of cultivation without soil. In fact, various nations have fought wars to wrest ownership of fertile land because land can guarantee wealth. India is the perfect example of this; it has many river basins with high runoff rivers throughout its length and breadth. River runoffs recharge basins with fertile silt through the mechanisms of floods. The country has suffered invasions throughout recorded history.

Gericke experimented first with flowers. The outcome of were sturdier flowering plants, more delicately colored with their maintained fragrance and free from Mildew - a kind of fungus that grows in conventional ways. In his published piece in Alabama's 'Anniston Star' newspaper, he grew wheat soilless with 300 – candle power argon-filled lamps to replace the need for sunlight in locations that lack sunlight. With the passage of time, and world's hunger for prosperity, and the need to feed growing populations, his work on soilless cultivation faded away.

H.H. Dunn in his article *'Plant "Pills" Grow Bumper Crops'* in Popular Science Monthly highlights work of Gericke's soilless research. He proposed chemical compositions that otherwise required in conventional farming can be supplemented in soilless agriculture. This chemical composition consisted of nitrogen, phosphorus, magnesia, iron, potassium, and sulfur (Dunn 1929: 30).

Gericke selected midwinter flowers like rose, pansies, sweat peas, and dahlias. He started his trial in 1928 and carried through 1929. The flowers were grown off season, with plant pills applied to the water pot and the plants flourished. Rose cutting grafted in water pots blossomed in 85 to 90 days (Dunn 1929: 30), wherein conventional practices allow roses to blossom in 8 to 12 weeks. (Norton 2017). The sweet peas grew from seed and bore fruit in 60 days, while conventionally it takes about 3 to 4 months to flower (SF Gate Contributor 2020); similarly, dahlias from seed blossomed in 90 to 110 days. Success in ornamental plants led Dunn to experiment with cereals and vegetables crops and with fruit-bearing shrubs and trees. His experiment with above mentioned crops also showed remarkable crop production with basic output characteristics of plants.

The size of asparagus stalks increased nearly by 100% without impairing the tenderness of the produce. Large-sized potatoes were achieved without enlarging the plants or altering the number of tubes. The tomato yield increased by 40% owing to the use of such techniques. Therefore, plants and crops grown in water had twice the rate of growth, with large size of the output, thereby enabling cultivators to opt for multi-cropping practices. The soilless water cultivation experiment with wheat, cotton, tobacco and cabbage experienced identical output. Cotton took 90 days to have full bolls (Dunn 1929: 30), in the conventional cropping pattern in USA it takes 150 to 180 days to have bolls. In the field, it takes 50-85 days from seed to first bud formation, 25-30 days for flower formation, and 50-60 days from flower opening to full boll (FAO 2020). In case of wheat, soilless farming boosted output by 50%.

These encouraging results won backing from the University of California. A team led by Dr. Gericke and his assistants was formed to formalize this research and amplify its outcomes. He enlarged the scope from Dunn's pot to tank production of food crops and its commercial viability. Dunn's experiment was of limited scope with individual crop pots. The tank production technique provided the opportunities to perform multi-cropping in the same tank, with separate rows. The experiment yielded about 150% to 200% more crops than could be grown in the area parameter of conventional farm-based agriculture (Dunn 1929: 30). The experiment also broke the myth that root crops only grow in soil as the main output is below the ground. Root crops like Carrot, Turnip, Beet Root, Radishes, Sugar Beat and parsnips showed same characteristics increase in output and quality as was observed in Dunn's trial with above mentioned crops. Vegetable crops such as Cabbage, Cauliflower, Celery and Lettuce however, did not demonstrate increased output, but registered rapidity of growth and size compared to soil-based cultivation (Dunn 1929: 30).

Besides increased crop production and quality, Dr. Gericke's trials provided for commercial viability of construction of concrete tank on one acre of land (this cost $250 in 1929). The construction of a concrete tank has life span of fifty years, and it wipes out the costs and labor associated with processes such as cultivation, irrigation, thinning, or weeding; tanks merely require to be filled with water and nutrients. Further, the rapidity of growth could eliminate the use of pesticides as this technique removes any scope for pests. However, we must note Gericke does not discuss pesticides because fossil fuels and their chemistry were still in nascent stages of development at that time.

The rapidity in growth would help to break in the cost in two to three seasons (Dunn 1929: 30, 150). Dr. Gericke goes on to suggest the ideal size of the tank (20x10 feet) with 6 inch depth. This technique helps to arrest the problems of soil variability, salinity, and soil recharge during flooding; hence, it offers freedom from environmental limitations that have traditionally attended agriculture. At same time, hydroponic does not eliminate the climatic requirement for the crops though it had experimented with artificial lighting. Probably the world had not garnered enough experience with indoor climate control systems, greenhouse systems, and lighting systems. However, it provides for more space for the plants per acre. For instance, Dr. Gericke could plant twenty thousand tomato plants in one acre area of tank compared to five thousand plants in one acre of soil.

The system being water based might give a picture of water guzzler to a lain man, but it is still very water efficient. A tank of 20x10 feet with 6 inch depth requires about 750 gallons or 2839.06 liters of water for 171 tomato plants. Even in the age of modern information technology, very few regions of world are able to gauge the full extent of crop water use. Dr. Gericke's system provides for precision water gauging. This amount of water (750 gallons) is insufficient to irrigate farmland half the size of a tank with an area of 20x10 feet. Given the same dimension of tank to land, farmland would produce only 60% of crop output when compared to tank production (Dunn 1292: 150).

Given the rains variability in the era of climate change, water harvesting from rain could be utilized for multi-cropping. The technology development over the century has increased the life span of water and scope of it. If the depth of the tank is raised with same amount of water, aquaculture can also be accommodated. This will help rejuvenate water with oxygen fixing techniques. Hydroponic is enhancement over drip irrigation (DI), subsurface drip irrigation (SDI) and mulching. It directs water and essential nutrients to roots of the which DI and SDI aims to achieve and eradicates weeding and water conservation – by arresting the evaporation of water with mulching. It could help in river restoration and power successful completion of water cycles as more land could be freed for forest growth, thus helping arrest the specter of climate change. Such techniques can feed the world faster and make agricultural produce more affordable.

In May 2000 FAO responded to the request of Ecuador, the country where in 1996 27% of urban population had unfulfilled basic needs, and 34% of urban poor were unable to afford basic family needs. The national average of fruits and vegetable intake per capita in country was 30 kg/person/year, the Latin American average at that time averaged around 60 kg/person/year (Stajano et.al. (NA): 1).

FAO and Uruguayan Hydroponic Association (ASUDHI) developed Simplified Hydroponic (SH) for quicker response to Ecuadorian call. It helped to generate a quick response but also achieved food production targets in smallest spans of time with high quality output. SH helped provide for nutrient requirement and also arrested the problem of affordability for common Ecuadorian families (Stajano et.al. (NA): 2).

The SH differs from the High Technology Hydroponic (HTH) which is prevalent in USA, Europe and Australia. The HTH is capital intensive and low labor based. SH is very low on capital investment and comparably more labor based. SH was developed to arrest the problem of unemployment and at same time providing the source of livelihood to Ecuadorian families (Stajano et.al. (NA): 2).

4 PERSONAL ENDEAVOUR

After this research article I personally tried hydroponics at my rooftop. I took necessary online classes to develop this skill set. I experimented with thermacol boxes with the water capacity of 45 liters. I tried with the brinjal as it is a hardy crop and grows well in open. Initially started with 40 seedlings but due unforeseen challenges only 6 matured to the plants. I lacked training of nutrient management, brinjal s did come out though as I used new concept of nano nutrients, where regular measuring of pH and EC/TDS of the water was avoided. The experiment failed and though I took training in the nutrient management but could not restart hydroponics on roof top. After some time to reengage in hydroponics I started with growing cattle fodder using hydroponics and found that growing 5kg of corn, wheat fodder the water footprint could be reduced by 99%. *This reduction in water use could be achieved by using tools that could mist the water drop.*

CONCLUSION

From Edison's light bulb to CFL and finally to LED bulbs, the evolution of technology took 125 years – that is, more than a century. In case of agriculture, the advancement to soilless cultivation it has taken almost 10,000 years and is still not very popular. Humans have been clearing forests to grow more food, thus disturbing nature's water cycles. Victor Schauberger says if you want to kill a river just clear the trees around it. It has been going around since the time when man stepped for settled life, started cultivation, and stopped food gathering and hunting. This activity of man's settled lifestyle now has led to climate change. The earlier climate changes were result of planetary movements and due to titling of the axis of the planet. The post Second World War period witnessed the race for prosperity, search for cheaper grounds for cultivation, and the drive to attain self-reliance in crops have gone for non-traditional cropping patterns, that is crops grown in foreign settings. This has led to excess water requirement for cultivation and made agriculture a water guzzler consuming 70% to 80% of world water sources. The manifestation of this activity was experienced within two decades after Second World War when the Aral Sea (the fourth largest lake on the planet) started receding in 1960s and low water runoff rivers started failing to reach their delta regions. The removal of forest cover and drying of lakes and rivers has destroyed 60% of biodiversity on the planet according to an article published 10th September 2020 in The Times of India. The brunt of this loss has been borne maximum by aquatic species as they have suffered 84% of decline.

Hydroponic if adopted by the collective efforts of society could help rivers to be free from the reservoirs that hold its water and be off grid. The water could be harvested from rain and dew thus eliminating need for canal that trans-grace the planet. This could free the land from canals where forests could come up and arrest the problem of climate change. The forest comes up on its own as experienced in Chernobyl where the nuclear accident took place in 1980s, the whole place was free from human civilization and forest has come up there.

The development of hydroponics, when viewed from the prism of Israel's experience and that of Jain irrigation efforts, allows us to appreciate the fact that less water is needed for modern farming crop if water gets directed to plant roots. This led to development of DI, SDI and Mulching. However, modern cultivation suffers from insects and pests because we have invaded their habitat and to overcome them, we have invented pesticides, insecticides, and herbicides to combat pests. This has only made our food poisonous and our health prone to disease like cancer. Various newspaper articles over the years have pointed out that Punjab in India has the highest number of cancer patients; the state is largest consumer of fertilizers and pesticides in India. It also suffers from low value returns for its produce despite being the largest producer of food crops in India. The wheat from Punjab is valued lower compared to the wheat coming from other states with low production and low consumption of fertilizers and pesticides.

The pests, insects, rodents and wild life will continue to invade our land as we have invaded their habitat. A classic example of this is the monkey invasion at Raisina hill buildings in New Delhi, India. Sir Richard Attenborough argues that in wake of wildlife conservation, we have neglected the species which lived below the ground, on land, water and air – these insects and their numbers are thrice that of all the species on ground, water and air.

To survive the era of China Virus pandemic, the tyranny of lies, heightened clash among the civilizations, media control on human intelligence and loss of livelihood hydroponic can be answer to this and to political apathy, quiet revolution and force back the apathetic political class, which profits from war mongering. The amount of money spent on weaponization has proved to be disastrous to human civilization; one example of this is the disintegration of the former USSR. Though it is a tough and long path as the resources have got concentrated in hand of very few in each society and they tender to use miss guide us that it is the rise in world population that has destroyed the environment. However, they hide the profit that gets generated from the products they force down on the population to satisfy its need.

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